AN-1271
APPLICATION NOTE

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Optimizing the ADuCM350 for Impedance Conversion

INTRODUCTION

The ADuCM350 is an ultralow power integrated mixed-signal metering solution that includes a microcontroller subsystem for processing, control, and connectivity. The processor subsystem is based on a low power ARM® Cortex™-M3 processor, a collection of digital peripherals, embedded SRAM and flash memory, and an analog subsystem which provides clocking, reset, and power management capability.

This application note details how to set up the ADuCM350 to optimally measure the impedance of an RC sensor using a 2-wire measurement approach. To optimize the accuracy of the impedance measurement, the user must maximize the usage of the16-bit ADC range. To do this, the peak-to-peak excitation output voltage, the R_{TIA}/C_{TIA} combination, and the calibration resistor all need to be calculated. The maximum allowed current into the load dominates the calculation.

If there is no limitation, then the user has the ability to maximize the amount of signal swing into the ADC from the transimpedance amplifier (TIA) to get the best SNR possible.

However, if there is a limitation on the load current, for example, to meet IEC 60601 standards in 2-wire, bio-impedance applications, then the user should calculate the maximum allowable current and use precautionary measures in the circuitry.

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REVISION HISTORY

3/14—Rev. 0 to Rev. A

Changes to Figure 5 6

12/13—Revision 0: Initial Version

DETAILS

SENSOR CONFIGURATION

In the example described in this application note, the user wants to measure the impedance of an RC type sensor with the configuration shown in Figure 1 for a 1 kHz excitation signal.

The sensor details are as follows:

C_P = 10 nF to 600 nF

R_P = 10 kΩ

R_S = 1 kΩ

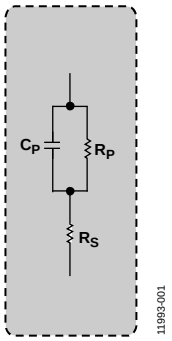

Figure 1. Sensor RC Configuration

CALCULATE THE MINIMUM IDEAL IMPEDANCE OF THE SENSOR

The first step is to calculate the lowest unknown impedance of the sensor. This allows the user to calculate the highest current signal into the TIA.

For the sensor in Figure 1, the impedance of the sensor is at its minimum when C_P = 600 nF.

To calculate the total impedance, Z_T, the first step is to calculate the impedance of the C_P capacitor.

$$Z_{Cp} = \frac{1}{2\pi f C_P} = -i265.26$$

where:
f is an excitation frequency of 1 kHz.
C_P is 600 nF.

Then, calculate the impedance of the parallel components $R_P \,||\, C_P$.

$$1/Z_P = 1/Z_{Rp} + 1/Z_{Cp}$$

or to simplify

$$Y_P = Y_{Rp} + Y_{Cp}$$

$$Y_{Rp} = 1/10{,}000$$

$$Y_{Cp} = 1/-i265.26$$

$$Y_P = 1\times 10^{-4} + i3.77 \times 10^{-3} \text{ (C lags by 90°)}.$$

To calculate the magnitude of Y_P

$$Magnitude = \sqrt{R^2 + I^2}$$

$$|Y_P| = 0.00377$$

Invert this to get

$$|Z_P| = 265.16\ \Omega$$

Calculate the phase of Y_P.

$$Phase\ (rads) = atan\ (I/R) = 1.544$$

$$Phase\ (degrees) = Phase\ (rads) \times \frac{180}{\pi} = -88.48°$$

$$Impedance\ of\ parallel\ RC = Z_P = 265.16\ \angle\ -88.48$$

Now, add the R_S series resistor.

$$Z_T = Z_P + Z_S$$

$$Z_P = 265.16\ \angle\ -88.48 = 7.03 - i265.06$$

$$Z_S = 1000\ \angle\ 0 = 1000 + i0$$

Add the two complex numbers.

$$Z_T = 1007.03 - i265.06 = 1041\ \angle\ -14.75$$

This is the lowest impedance realized by the part and it determines the maximum amount of current seen by the TIA.

RCAL CALCULATION

To calculate the RCAL value to calibrate the system, the lowest unknown impedance, Z, is used. If RCAL is equal to the magnitude of minimum impedance, the signal going into the DFT will be large. This improves repeatability and accuracy.

Therefore, an RCAL of ~1041 Ω is used for this example.

SCENARIO 1: NO LIMITATION ON LOAD CURRENT

Where there is no limitation on current seen by load, the maximum signal swing is used to maximize the SNR of ADC results.

- Maximum voltage swing is 600 mV peak.
- Highest signal current into TIA = 600 mV peak/1041 Ω = 0.576 mA peak.
- Peak voltage at output of TIA (maximum allowed by the ADuCM350) = 750 mV peak.
- R_{TIA} resistor to give peak 750 mV voltage for peak signal current:
  750 mV/0.576 mA = 1.302 kΩ

To improve the anti-aliasing performance and stability of the receive channel, an anti-aliasing capacitor is put in parallel with R_{TIA}. The 3 dB point of 80 kHz is selected (this is the maximum bandwidth of the system).

$$C_{TIA} = \frac{1}{2\pi f R_{TIA}} = \frac{1}{2\times\pi\times 80\ \text{kHz}\times 1.302\ \text{k}\Omega} = 1.5\ \text{nF}$$

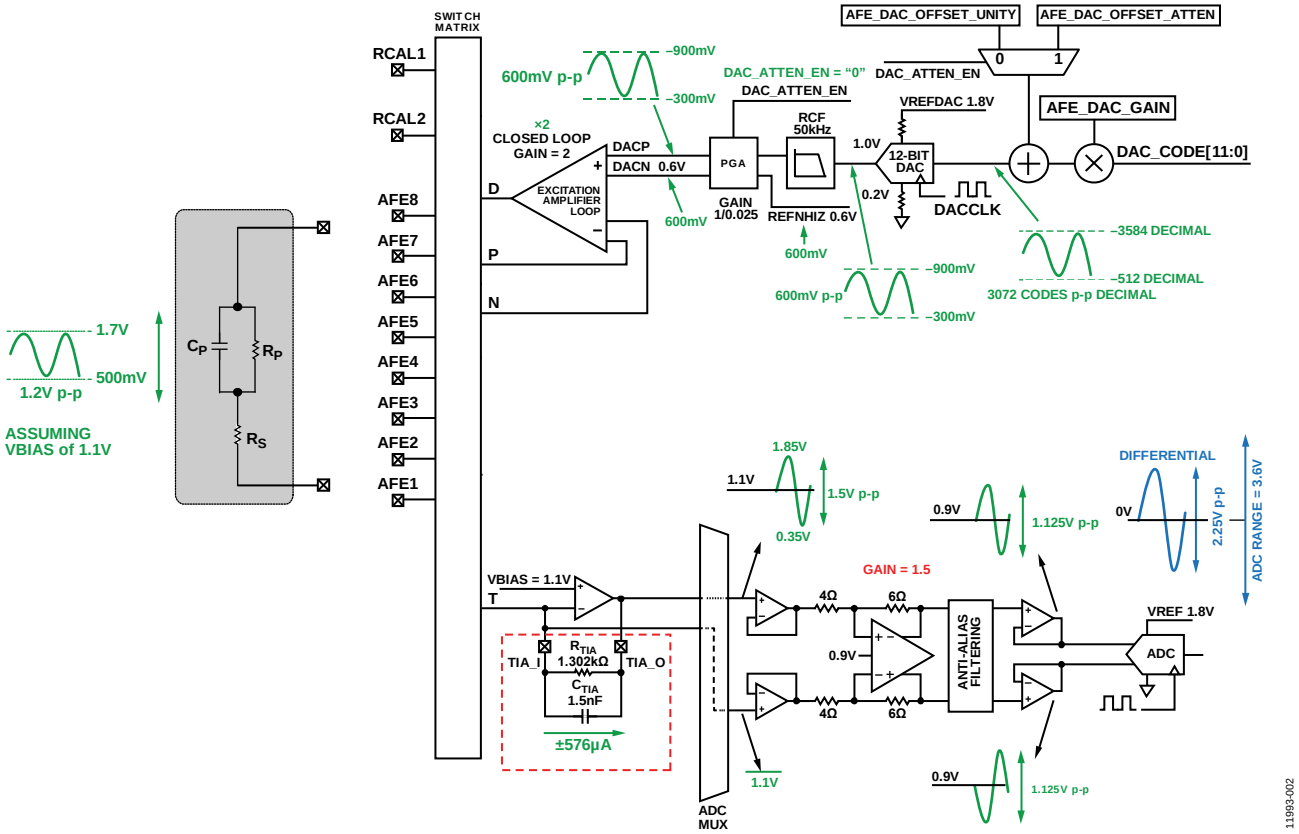

Figure 2. Signal Swings with No Limitation on Load Current

SCENARIO 2: LIMITED LOAD CURRENT

When there is a limitation on the load current, then a different approach is taken. In this example, the IEC 60601 bodily floating standard allows a maximum of 100 µA rms leakage. Thus, for this example, it is safe to assume that 50 µA rms/ 70.7 µA peak is the maximum current.

From a single fault correction perspective, with regard to the bodily floating standard, the following is included on each leg:

- 1 µF dc C_S blocking capacitor
- A series resistor representing some form of leads (R_{LEAD})

Connect an extra current limiting series resistance of 200 Ω to the drive leg, R_{LIMIT}.

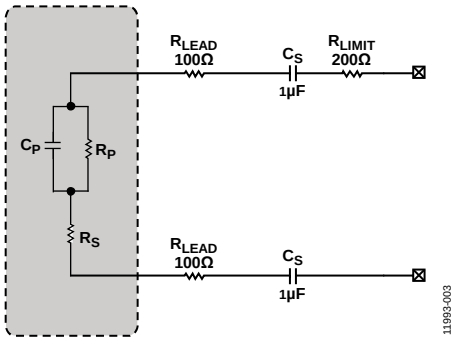

Figure 3. Sensor with Single Fault External Protection

Minimum impedance of the sensor remains at 1041 Ω. The series components now add to this minimum impedance seen by the ADuCM350 TIA.

Calculating the impedance of extra circuitry in the network gives

200 Ω + 100 Ω +100 Ω + 1 µF + 1 µF

Assume an excitation frequency of 1 kHz.

Capacitors are in series, thus

$$C_T = (C1 \times C2)/(C1 + C2)$$

where C_T = 0.5 µF.

$$Z_C = 1/(2\ \pi f C_T) = 1/(2 \times \pi \times 1\ \text{kHz} \times 0.5\ \mu\text{F}) = -i318.3$$

$$R_T = R_{LIMIT} + R_{LEAD} + R_{LEAD} = 400$$

Total extra circuitry impedance = 400 –i318.3

The minimum impedance seen by the TIA is the minimum sensor impedance plus the minimum extra circuitry impedance converter.

$$Z_T = (400 - i318.3) + (1007.03 - i265.06) = 1407 - i583.4$$

$$= 1523\ \angle\ -22.5$$

This is the minimum impedance seen by the ADuCM350. For safety reasons, reduce this by 20% to avoid unwanted over-ranging of ADC results.

Therefore, a minimum impedance of 1218.4 Ω is assumed. The Cortex-M3 flags any impedance measurement below value as an invalid result. Check the connections because the flag indicates that the ADC has overranged or encountered another error.

Therefore, to allow a maximum of 70.7 µA peak with a minimum impedance of 1218.4 Ω, a sinewave amplitude is needed.

$$70.7 \times 10^{-6} \times 1218.4\ \Omega = 86\ \text{mV peak}$$

Note that the maximum allowed sinewave amplitude when the DAC attenuator is enabled, DAC_ATTEN = 1, is 15 mV peak. Because 86 mV peak exceeds this value, there are two options. The first option is to use 15 mV peak with a reduced signal-to-noise ratio. The second option is to disable the DAC attenuator and select 86.5 mV peak in nonattenuation mode. The downside of this is that the LSB size increases 40 times.

Nonattenuator mode

$$\textit{LSB size} = 1.6\ \text{V}/2^{12} = 390\ \mu\text{V p-p} = 195\ \mu\text{V peak}$$

Attenuator mode

$$\textit{LSB size} = 1/40\ (1.6\ \text{V}/2^{12}) = 9.76\ \mu\text{V p-p} = 4.88\ \mu\text{V peak}$$

With a bigger LSB size, there is less resolution of measurement, thus more quantization noise in creating the sinewave and measuring the response.

Continuing with this example, proceed using a 15 mV peak sinwave with attenuation enabled (DAC_ATTEN = 1).

Calculate the current seen by TIA.

$$15\ \text{mV peak}/1218.4\ \Omega = 12.3\ \mu\text{A peak signal}$$

Then, calculate the R_{TIA} and C_{TIA} to optimize the ADC range where the R_{TIA} resistor gives the peak 750 mV voltage signal current.

$$750\ \text{mV}/12.3\ \mu\text{A} = 60.98\ \text{k}\Omega$$

To improve the anti-aliasing performance and improve the stability of the receive channel, an anti-aliasing capacitor is put in parallel to R_{TIA}. The 3 dB point of 80 kHz is selected (the maximum bandwidth of the system).

$$C_{TIA} = 1/2\pi f R_{TIA}$$

$$= 1/\ (2\pi \times 80\ \text{kHz} \times 60.98\ \text{k}\Omega)$$

$$= 32.6\ \text{pF}$$

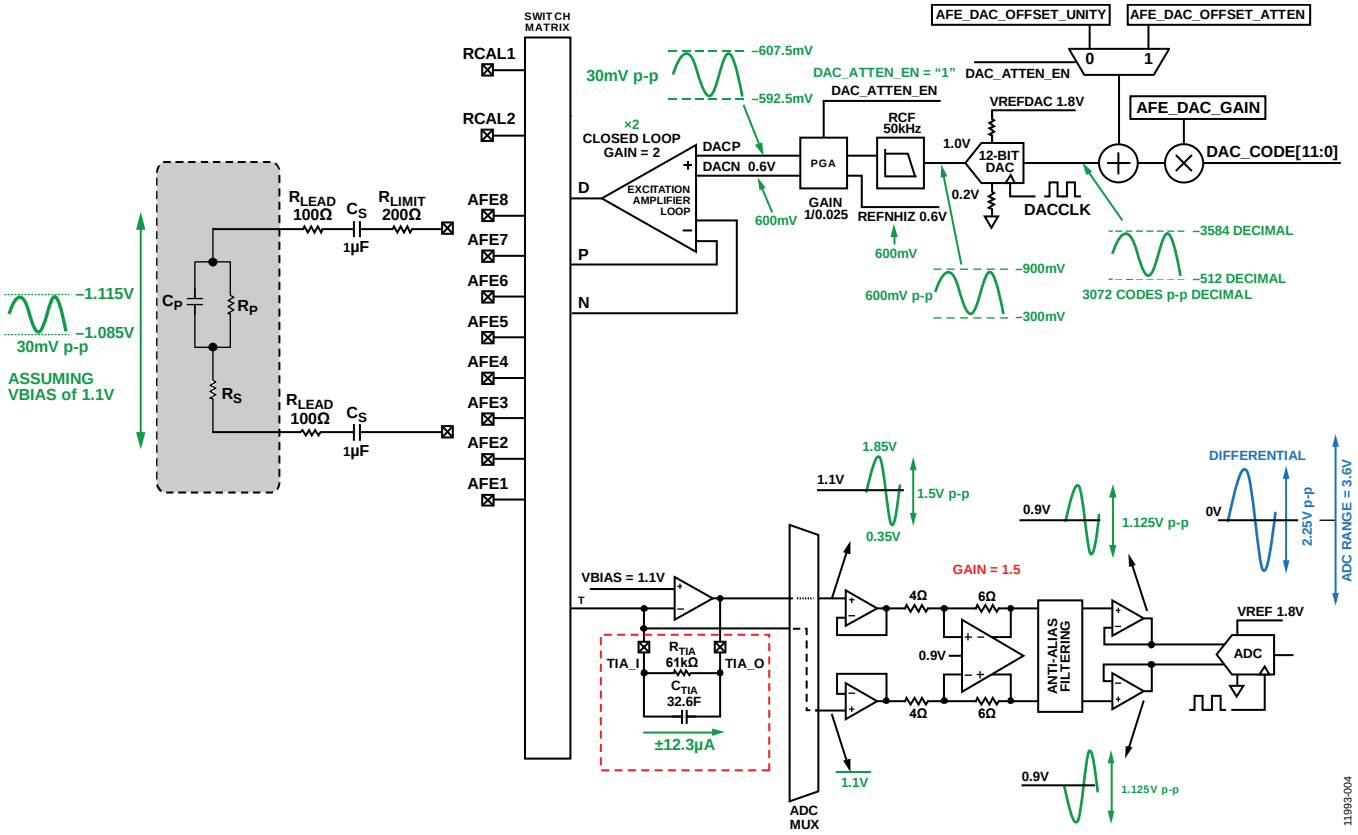

Figure 4. Signal Swings When Limitation On Load Current

IMPEDANCE MEASUREMENT EXAMPLE IN LABVIEW

The ADuCM350 LabVIEW® GUI can measure impedance and rapidly prototype sensor measurement.

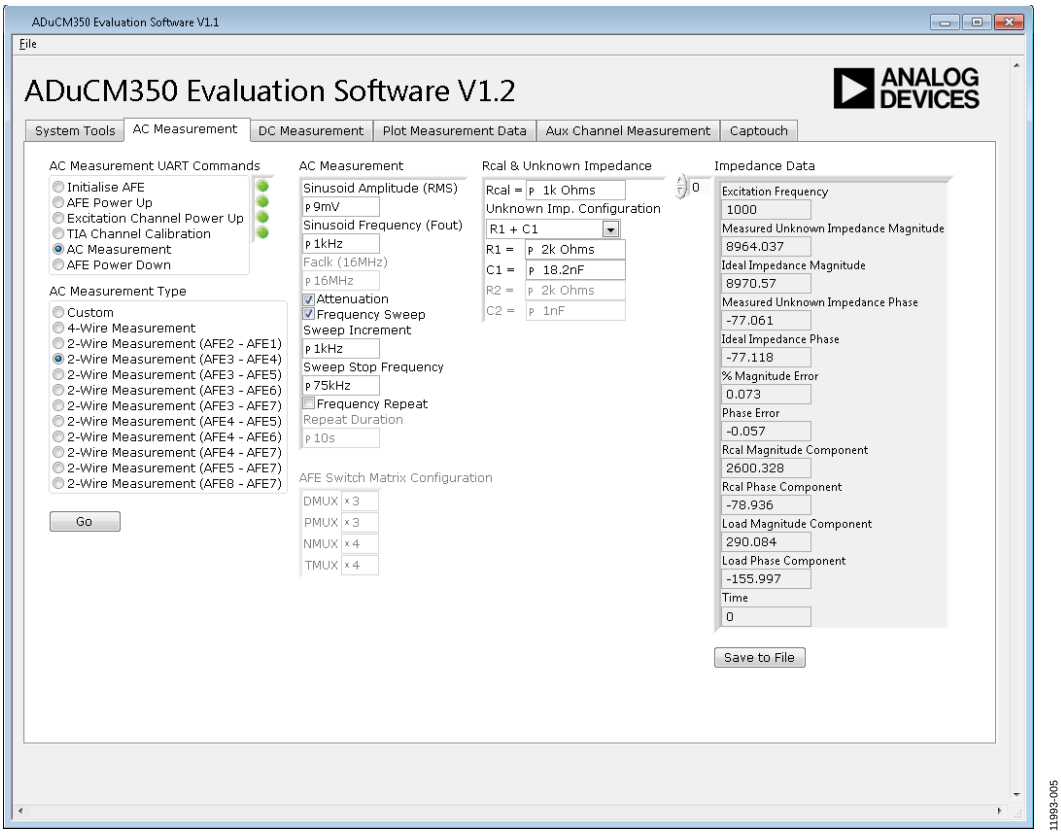

Figure 5. LabVIEW Impedance Measurement AFE Control

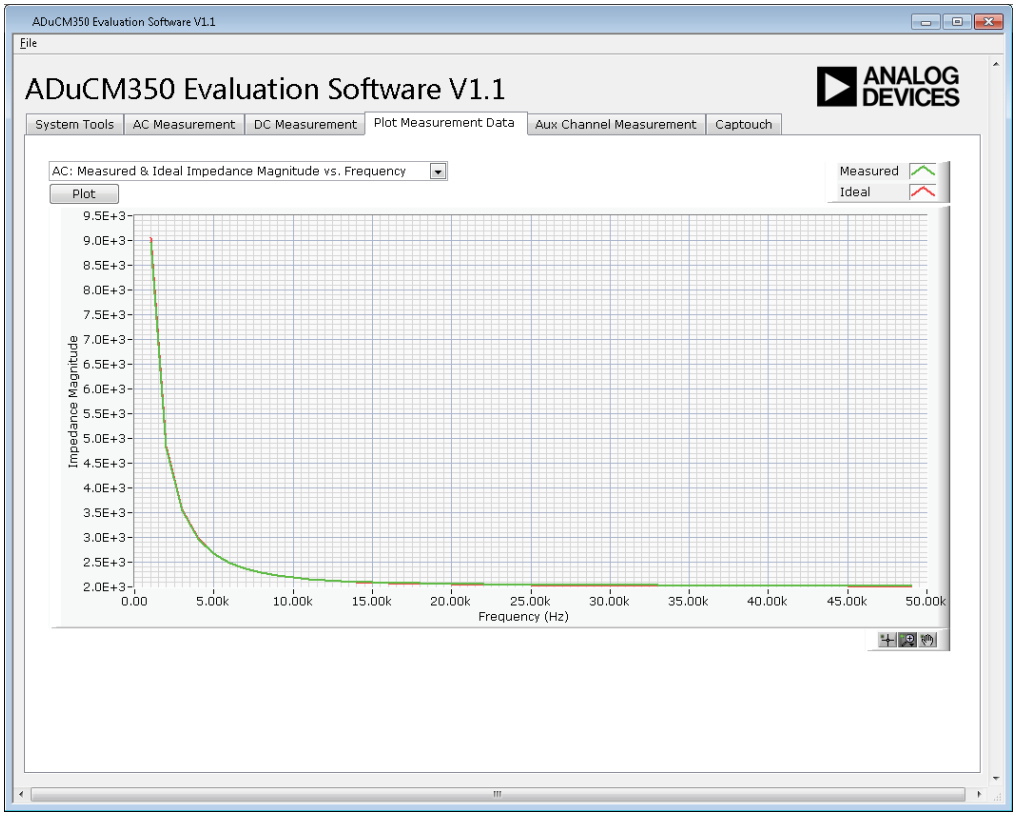

Figure 6. LabVIEW Impedance Measurement

IMPEDANCE MEASUREMENT EXAMPLE IN SOFTWARE DEVELOPMENT KIT

The IAR embedded workbench based software development kit includes an ImpedanceMeasurement_2Wire example. This example verifies the performance of the impedance converter on the ADuCM350.

The sequence for the example is measuring three unknown 2-wire impedances.

- AFE3 to AFE4
- AFE4 to AFE5
- AFE5 to AFE6

The code has easy programmability for excitation frequency, excitation voltage, and RCAL value. It is possible to code other changes to the measurement into the measurement sequence. The readme section of this example project provides more details.

Figure 7 shows an example measurement. Both real and imaginary components are calculated.

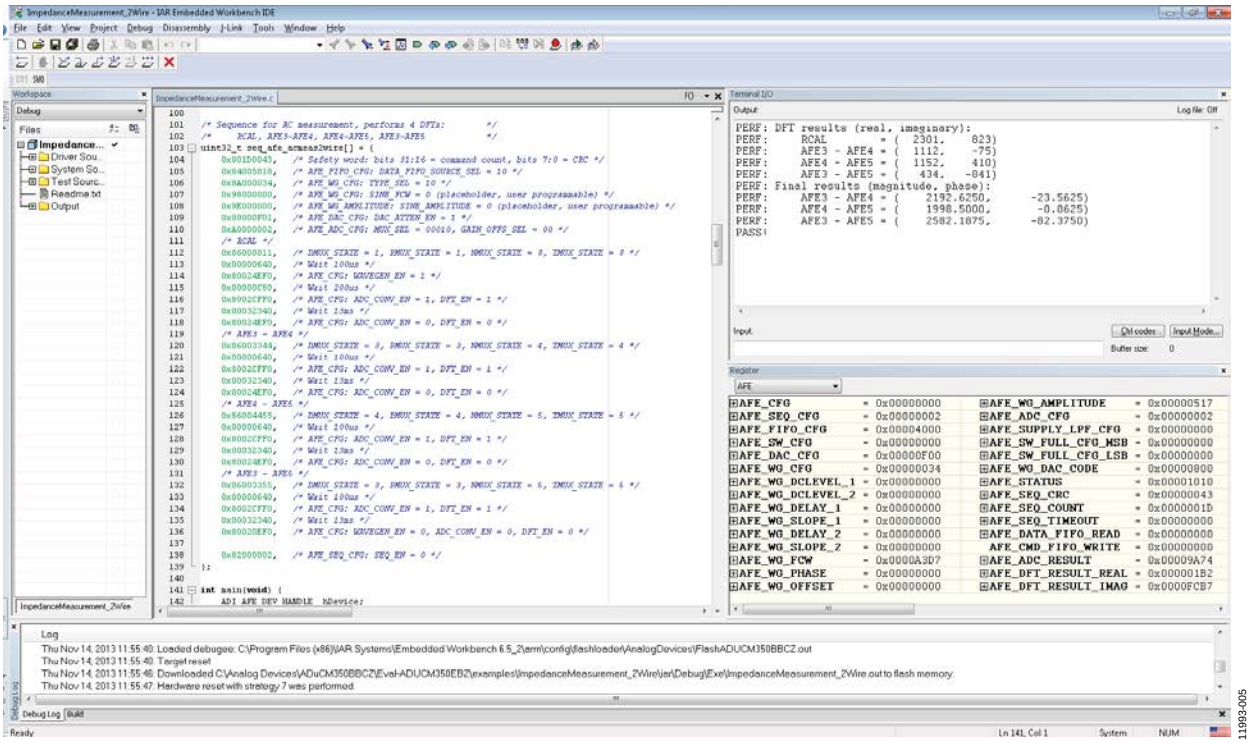

Figure 7. Signal Swings When Limited On Load Current

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